PARIS-MB User Manual

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1 Instrument Description

The PARIS Multi-Band receiver is a GNSS reflection receiver capable of operating at L-band and other higher (C/X/K) bands. Its signal processor implements the so-called interferometric technique [1] (PARIS-IT), that consists of cross-correlating the direct and reflected signals received by the up-looking and down-looking antennas, respectively. This instrument has been designed and manufactured at the Institut of Space Sciences (CSIC/IEEC) [3].

Figure 1 shows a block diagram of the instrument. It consists of a 19 inch rack of 3U height (labelled PARIS-MB S/P), with external additional hardware. This 19 inch rack is a dual channel L-band receiver, capable of receiving and down-converting radio signals in a sub-band of 4-40 MHz base-band bandwidth, between 1-2 GHz. Gain and bandwidth of both down-conversion chains are programmable. The instrument can operate at a higher band by using external Low Noise Blocks (LNB's) [1] that shift the signals from X-band, or any other desired band to a frequency between 1 GHz and 2 GHz. The receiver does also provides 10 MHz coherent reference clocks to feed the LNB's, so that the down-conversion from a high frequency band is coherent with the system's local oscillator and clocks. Any desired antenna (horn feed, horn feed with dish reflectors,. . .) can be connected at the input of the LNB's.

The receiver samples each in-phase and quadrature component of both base-band down-converted signals at 80 Msamples/second and quantizes them using 10 bits per sample. Only the three most significant bits are used in further signal processing.

[1] An LNB is a low noise amplifier followed by a down-conversion stage to intermediate frequency.

The digital signal processor computes the complex cross-correlation between both signals in a 200 lags window. Lag separation corresponds to one sampling period, that is, 1/80 MHz = 12.5 ns. The origin of the correlation window is selectable (from 0 lags to 255 lags) by programming individually an additional delay to each signal. A new cross-correlation is computed every millisecond. An embedded GPS receiver delivers GPS time information to the system and the obtained cross-correlation waveforms are time-tagged accordingly. Finally, the data is saved in real-time to an external (laptop) computer through an Ethernet connection.

The system's power supply is a 19 inch rack of 2U height, and it is supplied with 220V AC. The power supply is labelled *PARIS-MB P/S*. Figure 2 shows a picture of the the system.

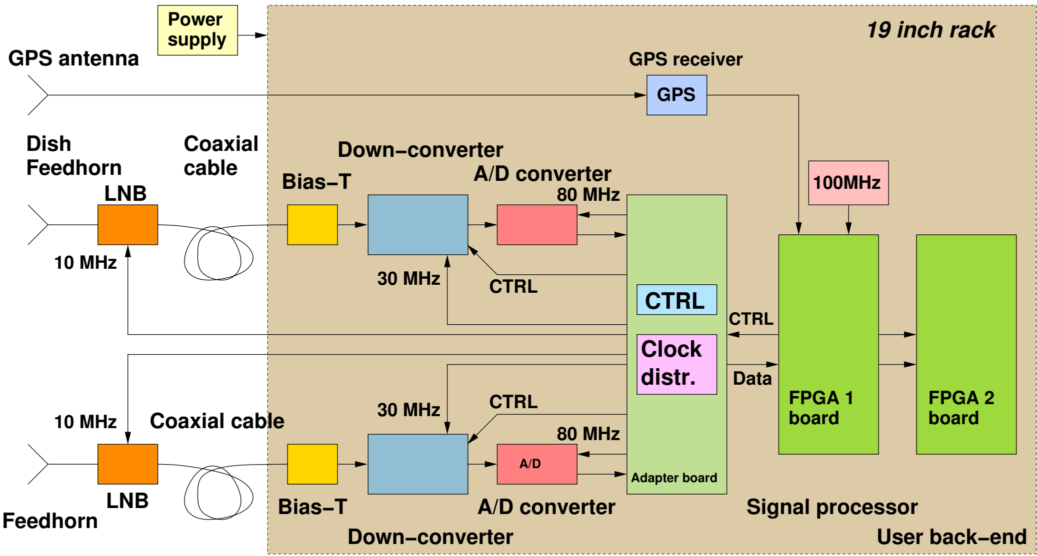

Figure 1: Block diagram of the PARIS-MB receiver.

2 Interfaces

Figure 2 shows a picture with all external interfaces at the front panels of the receiver and power supply. Their names and functions are shown in table 1.

Figure 2: Picture of the PARIS-MB receiver.

3 Data Format

The data collected by the PARIS-MB receiver is saved in two types of NetCDF files:

***.WAVMB.nc** Contains waveforms and calibration data for a complete minute. Data rate within the file is 1 ms

***.STSMB.nc** Contains instrument status information for a complete minute. Data rate within the file is 1 s.

3.1 *.WAVMB.nc File Format

The NetCDF data format for the waveform files consists of an array of entries, where each entry corresponds to a time-tagged complex waveform (1 ms real-time integrated) with its corresponding simultaneous Offset and PMS measurements. The contents of each field is described below:

week : is the GPS week at which the measurement has been taken.

sow : is the GPS second of week at which the measurement has been taken.

Table 1: External interfaces.

Connector	**Function**	**Type**
Receiver		
J1	RF1 (up), supply LNB	TNC female
J2	10MHz reference (RF1)	TNC female
J3	10MHz reference (RF2)	TNC female
J4	RF2 (down), supply LNB	TNC female
J5	GPS (for external GPS antenna)	TNC female
J6	Keyboard	PS/2
J7	Screen	VGA, DE-15
J8	Ethernet 1: 192.168.63.62 (CTRL)	RJ-45
J9	Ethernet 2: 192.168.63.61	RJ-45
J10	Power Supply Input	Circular multi-pin male
Power Supply		
J1	220V	Circular, three pins
J2	Supply to Receiver	Circular multi-pin female
F	Fuse (3.15A)	

millisecond : is the millisecond within the current sow at which the measurement has been taken.

offset_iup : is the DC value measurement of the in-phase component of the *up* signal for the current millisecond. The DC signal offset value O for signal $x[n]$ is measured using this formula:

$$P = \frac{1}{k_o} \sum_{0}^{N-1} x[n] \tag{1}$$

where $N = 79,796$ is the number of signal samples integrated in 1 ms. The signal $s[n]$ is quantized using ten bits per sample but just the three MSB are used to compute the DC offset. After N consecutive accumulations in a 22 bits register 16 bits are read out from this register. These are bits 17 down to 2. The value $k_o = 4$ takes this into account.

offset_qup : is the DC value measurement of the quadrature component of the *up* signal for the current millisecond. The DC signal offset value O for signal $x[n]$ is measured using the same formula as for **offset_iup**.

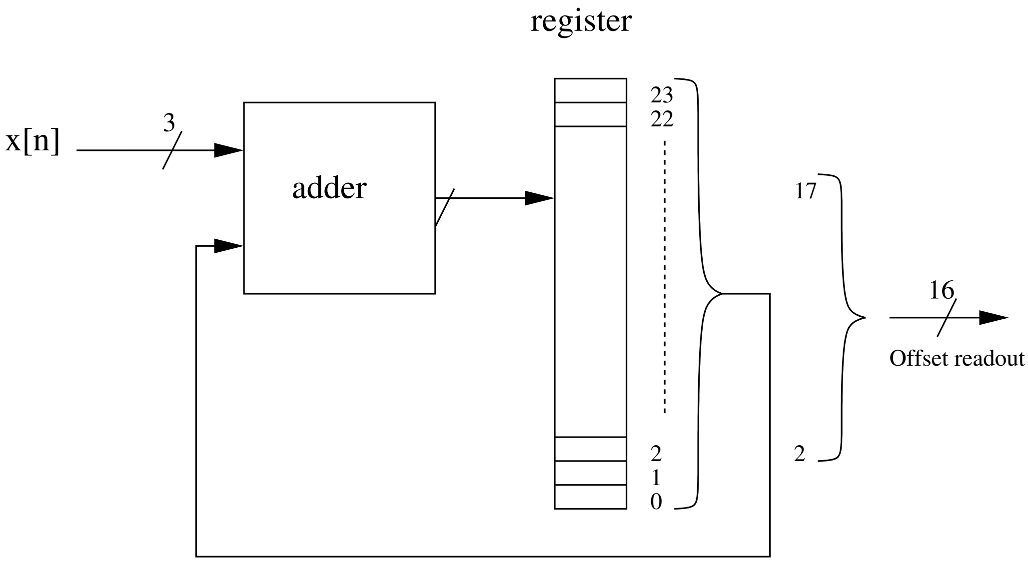

Figure 3: Block diagram of the signal DC offset measurement circuit.

offset_qdw : is the DC value measurement of the in-phase component of the *down* signal for the current millisecond. The DC signal offset value O for signal $x[n]$ is measured using the same formula as for **offset_iup**.

offset_qdw : is the DC value measurement of the in-phase component of the *down* signal for the current millisecond. The DC signal offset value O for signal $x[n]$ is measured using the same formula as for **offset_iup**.

pms_iup : is the total power measurement of the in-phase component of the *up* signal for the current millisecond. The total power P for signal $x[n]$ is measured by using this formula:

$$P = \frac{1}{k_p} \sum_{0}^{N-1} x^2[n] \tag{2}$$

where $N = 79,796$ is the number of signal samples integrated in 1 ms. It must be taken into account that the signal $s[n]$ is quantized using ten bits per sample but just the three MSB are used to compute the power value. After N consecutive accumulations in a 22 bits register the 16 MSB of this register are the read out value. The value $k_p = 64$ takes this into account.

pms_qup : is the total power measurement of the quadrature component of the *up* signal for the current millisecond. It is measured in the same way as **pms_iup**.

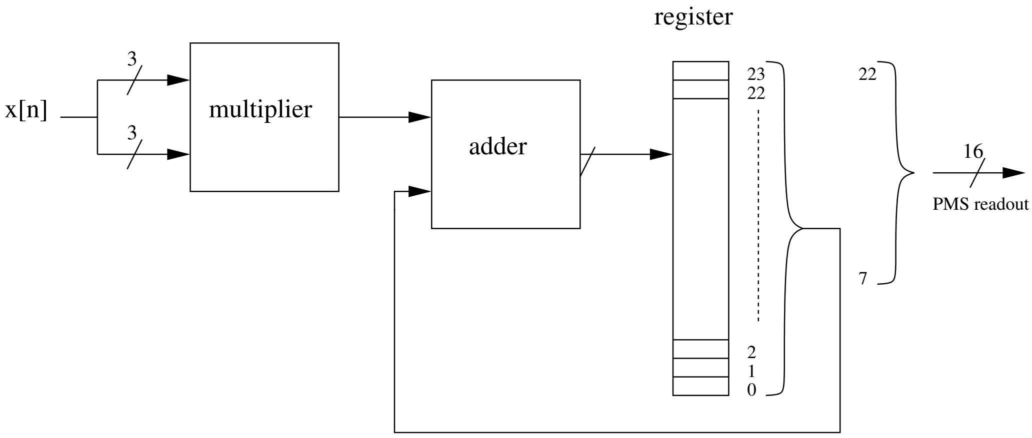

Figure 4: Block diagram of the PMS measurement circuit.

pms_idw : is the total power measurement of the in-phase component of the *down* signal for the current millisecond. It is measured in the same way as **pms_iup**.

pms_qup : is the total power measurement of the quadrature component of the *down* signal for the current millisecond. It is measured in the same way as **pms_iup**.

ii is the real cross-correlation term between the in-phase component of the *up* signal and the in-phase component of the *down* signal for the current millisecond. The real cross-correlation at lag m, $R[m]$ is measured using this formula:

$$R[m] = \frac{1}{k_r} \sum_{0}^{N-1} y[n]x[n-m] \tag{3}$$

where $N = 79,796$ is the number of signal samples integrated in 1 ms. The three MSB bits of the input signals are used to compute the product, and the accumulation register is 23 bits broad (22 bits plus one sign bit). The 16 MSB of this register are read out, so $k_r = 64$.

3.2 *.STSMB.nc File Format

The NetCDF data format for the status files consists of an array of entries, where each entry corresponds to the status of the instrument for a given second. The contents of each field is described below:

x : is the x coordinate of the receiver position expressed in the ECEF (GPS) frame.

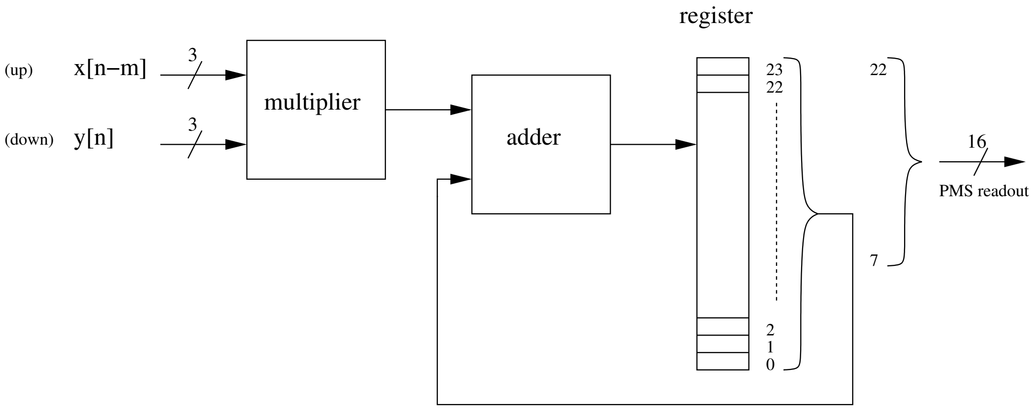

Figure 5: Block diagram of one single correlator lag.

y : is the y coordinate of the receiver position expressed in the ECEF (GPS) frame.

z : is the z coordinate of the receiver position expressed in the ECEF (GPS) frame.

week : is the GPS week at which the measurement has been taken.

sow : is the GPS second of week at which the measurement has been taken.

pv : is a boolean that indicates if the time (**week**, **sow**) and position (**x**, **y**, **z**) are valid.

N : The local oscillator frequency is obtained by programming the MAX2112 mixing stage [2]. The local oscillator frequency F_{LO} is obtained from the mixer frequency $F_{MIX} = F_{REF}$ by using the formula

$$F_{LO} = MF_{REF} \tag{4}$$

where M is a rational multiplier. N is the integer part of M.

F : The local oscillator frequency is obtained by programming the MAX2112 mixing stage [2]. The local oscillator frequency F_{LO} is obtained from the mixer frequency $F_{MIX} = F_{REF}$ by using (4). F is the fractional part of M.

BW : The bandwidth of the down-conversion chain can selected by programming the MAX2112 mixing stage. This field holds the value of register 9 (LPF) of the MAX2112 down-converter [2]. The actual 3dB bandwidth is obtained by using the formula

$$f_{-3dB} = 4\ \text{MHz} + (BW - 12) \cdot 0.290\ \text{MHz} \tag{5}$$

BBG_up : The gain of the MAX2112 mixing stage can be adjusted at baseband by programming its control register (bits BBG) [2]. This field holds the baseband gain for the up channel expressed in dB (from 0dB to 15dB in 1dB steps).

BBG_up : The gain of the MAX2112 mixing stage can be adjusted at baseband by programming its control register (bits BBG) [2]. This field holds the baseband gain for the down channel expressed in dB (from 0dB to 15dB in 1dB steps).

VAS : The MAX2112 down-conversion stage includes 24 VCOs. The local oscillator frequency can be manually selected, and by setting the VAS bit to logic '1'the MAX2112 selects automatically the appropriate VCO. [2].

freq : Most recent estimation of the reference clock frequency. Nominal frequency is $F_{REF} = 80$MHz. Frequency count is given in counts per minute minus 2^{32}. So, a reading of 505,032,893 corresponds to a reference frequency of $F_{REF} = \frac{505{,}032{,}893+2^{32}}{60} = 80,000,003.15$ MHz.

LNB_fact A 10MHz frequency is delivered to the LNB blocks to generate the local oscillator frequency of the LNB F_{LNB}. This LNB local oscillator frequency is obtained by multiplying the 10MHz frequency by a multiplication factor.

$$F_{LNB} = LNB_{fact} 10 \text{ MHz} \tag{6}$$

GRF_coarse_up : The gain of the MAX2112 down-converter can be adjusted at RF by setting a control voltage [2]. This is accomplished by using two digitally programmable potentiometers, one for coarse adjustment of the voltage and a second one for fine adjustment. This variable holds the programming value for the coarse adjustment of the up chain.

GRF_fine_up : The gain of the MAX2112 down-converter can be adjusted at RF by setting a control voltage [2]. This is accomplished by using two digitally programmable potentiometers, one for coarse adjustment of the voltage and a second one for fine adjustment. This variable holds the programming value for the fine adjustment of the up chain.

GRF_coarse_dw : The gain of the MAX2112 down-converter can be adjusted at RF by setting a control voltage [2]. This is accomplished by using two digitally programmable potentiometers, one for coarse adjustment of the voltage and a second one for fine adjustment. This variable holds the programming value for the coarse adjustment of the dw chain.

GRF_fine_up : The gain of the MAX2112 down-converter can be adjusted at RF by setting a control voltage [2]. This is accomplished by using two digitally programmable potentiometers, one for coarse adjustment of the voltage and a second one for fine adjustment. This variable holds the programming value for the fine adjustment of the dw chain.

RUN : This boolean variable indicates if the correlator was running.

LSB : The correlation data is accumulated in a 23-bits register, but only 16 bits are read-out. This variable shows the LSB bit that is being read out from the accumulator.

TEST : Indicates whether an external signal is used ('0') or an internal test signal ('1').

SRC_UP : Meaningful only when TEST='0'. If SRC_UP='1' the signal input into connector J1 (up) is used, otherwise the signal input into connector J4 (down).

SRC_DW : Meaningful only when TEST='0'. If SRC_DW='1' the signal input into connector J1 (up) is used, otherwise the signal input into connector J4 (down).

I_UP_A0 : This is the filter coefficient a_q for $q = 0$ in (7), for the in-phase component of the up signal. All signal components are digitally filtered digitally (FIR/IIR) before being cross-correlated. The filter function is

$$\sum_{q=0}^{Q} a_q z[n-q] = \sum_{p=0} b_p x[n-p] \tag{7}$$

where $x[n]$ is the input signal and $z[n]$ the output signal.

I_UP_A1 : This is the filter coefficient a_q for $q = 1$ in (7), for the in-phase component of the up signal.

I_UP_A2 : This is the filter coefficient a_q for $q = 2$ in (7), for the in-phase component of the up signal.

I_UP_A3 : This is the filter coefficient a_q for $q = 3$ in (7), for the in-phase component of the up signal.

I_UP_B0 : This is the filter coefficient b_p for $p = 0$ in (7), for the in-phase component of the up signal.

I_UP_B1 : This is the filter coefficient b_p for $p = 1$ in (7), for the in-phase component of the up signal.

I_UP_B2 : This is the filter coefficient b_p for $p = 2$ in (7), for the in-phase component of the up signal.

I_UP_B3 : This is the filter coefficient b_p for $p = 3$ in (7), for the in-phase component of the up signal.

Q_UP_A0 : This is the filter coefficient a_q for $q = 0$ in (7), for the quadrature component of the up signal.

Q_UP_A1 : This is the filter coefficient a_q for $q = 1$ in (7), for the quadrature component of the up signal.

Q_UP_A2 : This is the filter coefficient a_q for $q = 2$ in (7), for the quadrature component of the up signal.

Q_UP_A3 : This is the filter coefficient b_p for $q = 3$ in (7), for the quadrature component of the up signal.

Q_UP_B0 : This is the filter coefficient b_p for $p = 0$ in (7), for the quadrature component of the up signal.

Q_UP_B1 : This is the filter coefficient b_p for $p = 1$ in (7), for the quadrature component of the up signal.

Q_UP_B2 : This is the filter coefficient b_p for $p = 2$ in (7), for the quadrature component of the up signal.

Q_UP_B3 : This is the filter coefficient b_p for $p = 3$ in (7), for the quadrature component of the up signal.

I_DW_A0 : This is the filter coefficient a_q for $q = 0$ in (7), for the in-phase component of the down signal.

I_DW_A1 : This is the filter coefficient a_q for $q = 1$ in (7), for the in-phase component of the down signal.

I_DW_A2 : This is the filter coefficient a_q for $q = 2$ in (7), for the in-phase component of the down signal.

I_DW_A3 : This is the filter coefficient a_q for $q = 3$ in (7), for the in-phase component of the down signal.

I_DW_B0 : This is the filter coefficient b_p for $p = 0$ in (7), for the in-phase component of the down signal.

I_DW_B1 : This is the filter coefficient b_p for $p = 1$ in (7), for the in-phase component of the down signal.

I_DW_B2 : This is the filter coefficient b_p for $p = 2$ in (7), for the in-phase component of the down signal.

I_DW_B3 : This is the filter coefficient b_p for $p = 3$ in (7), for the in-phase component of the down signal.

Q_DW_A0 : This is the filter coefficient a_q for $q = 0$ in (7), for the quadrature component of the down signal.

Q_DW_A1 : This is the filter coefficient a_q for $q = 1$ in (7), for the quadrature component of the down signal.

Q_DW_A2 : This is the filter coefficient a_q for $q = 2$ in (7), for the quadrature component of the down signal.

Q_DW_A3 : This is the filter coefficient b_p for $q = 3$ in (7), for the quadrature component of the down signal.

Q_DW_B0 : This is the filter coefficient b_p for $p = 0$ in (7), for the quadrature component of the down signal.

Q_DW_B1 : This is the filter coefficient b_p for $p = 1$ in (7), for the quadrature component of the down signal.

Q_DW_B2 : This is the filter coefficient b_p for $p = 2$ in (7), for the quadrature component of the down signal.

Q_DW_B3 : This is the filter coefficient b_p for $p = 3$ in (7), for the quadrature component of the down signal.

delay_offset : The up signal can be delay by an integer amount of clock cycles (lags). This value indicates the magnitude of the delay.

delay_up_0 : Constant group delay component (d_0) applied to the up signal during the current second (see equation (8)). The signal processor applies a dynamic group delay to the input signals, which is modelled by a polynomial

$$\tau = d_0 + d_1 t + d_2 t^2 \tag{8}$$

delay_up_1 : Linear group delay component (d_1) applied to the up signal during the current second (see equation (8)).

delay_up_2 : Quadratic group delay component (d_2) applied to the up signal during the current second (see equation (8)).

phase_up_0 : Constant phase component (ϕ_0) applied to the up signal during the current second (see equation (9)). The signal processor applies a dynamic phase model to the input signals, which is modelled by a polynomial

$$\phi = \phi_0 + \phi_1 t + \phi_2 t^2 \tag{9}$$

phase_up_1 : Linear phase component (d_1) applied to the up signal during the current second (see equation (9)).

phase_up_2 : Quadratic phase component (d_2) applied to the up signal during the current second (see equation (9)).

delay_dw_0 : Constant group delay component (d_0) applied to the down signal during the current second (see equation (8)).

delay_dw_1 : Linear group delay component (d_1) applied to the down signal during the current second (see equation (8)).

delay_dw_2 : Quadratic group delay component (d_2) applied to the down signal during the current second (see equation (8)).

phase_dw_0 : Constant phase component (ϕ_0) applied to the down signal during the current second (see equation (9)).

phase_dw_1 : Linear phase component (d_1) applied to the down signal during the current second (see equation (9)).

phase_dw_2 : Quadratic phase component (d_2) applied to the down signal during the current second (see equation (9)).

References

[1] M. Martin-Neira, S. D'Addio, C. Buck, N. Floury, and R. Prieto-Cerdeira. The PARIS Ocean Altimeter In-Orbit Demonstrator. *Geoscience and Remote Sensing, IEEE Transactions on*, 49(6):2209 –2237, June 2011.

[2] MAX2112 Complete, Direct-conversion Tuner for DVBS2 Applications. Technical report, Maxim, 2010.

[3] Serni Ribo, Juan Carlos Arco, Santi Oliveras, Antonio Rius, and Christopher Buck. Experimental results of an X-band PARIS receiver using digital satellite TV opportunity signals scattered on the sea surface. *Submitted to Geoscience and Remote Sensing, IEEE Transactions on*, 2013.